[redacted]

1.

$$\Delta H + \Delta E_K + \cancel{\Delta E_p}^{\to 0} = Q - \cancel{W_s}^{\to 0}$$

$$\Delta H + \Delta E_K = Q$$

from steam tables

$\hat{H}(H_2O(l), 24°C, 10bar) = 100.6\ kJ/kg$

$\hat{H}(10bar, \text{saturated steam}) = 2776.2\ kJ/kg$

$$\Delta \hat{H} = 2776.2\ \frac{kJ}{kg} - 100.6\ \frac{kJ}{kg}$$

$$\boxed{\Delta \hat{H} = 2675.6\ \frac{kJ}{kg}}$$

$$u_f = \frac{\dot{V}}{A} = \frac{15000\,m^3/h\left(\frac{1h}{3600s}\right)}{0.25\pi(15\times10^{-2}cm)^2} = 235.8\,m/s$$

from steam tables, $\hat{V}(10bar, \text{saturated steam}) = 0.1943\ m^3/$

$$\dot{m} = (15000\,m^3/h)\left(\frac{1kg}{0.1943m^3}\right)\left(\frac{1h}{3600s}\right) = 21.44\,kg/s$$

$$\Delta E_K = \frac{1}{2}\dot{m}u_f^2 - 0$$

$$= \frac{1}{2}(21.44)(235.8)^2$$

$$= 5.96\times10^5\ J/s$$

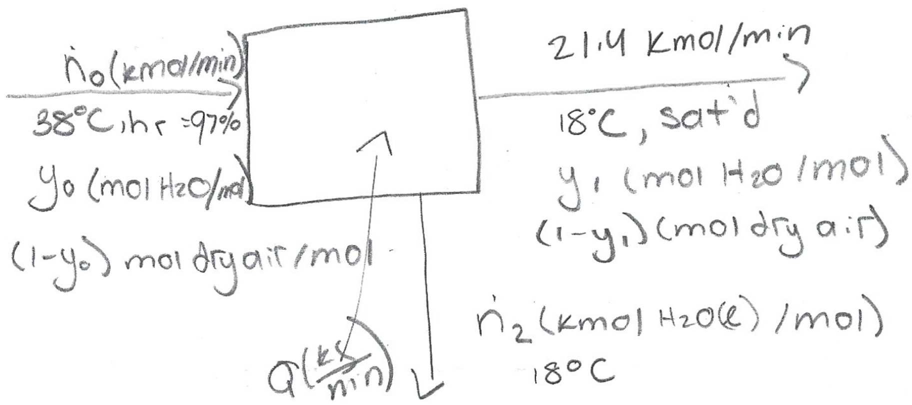
$$Q = \Delta H + \Delta E_k$$

$$= \dot{m}\Delta\hat{H} + \Delta\dot{E}_k$$

$$= (21.44\ \tfrac{kg}{s})(2675.6\ \tfrac{kJ}{kg}) \times \frac{1000\,J}{1\,kJ} + 5.96\times10^5\ J/s$$

$$\boxed{Q = 5.80 \times 10^7\ W}$$

2a)



basis: $510\ \frac{m^3}{min} \times \frac{273K}{291K} \times \frac{10^3 L}{m^3} \times \frac{1\,mol}{22.4\,L\,(STP)} \times \frac{1\,kmol}{10^3\,mol}$

$= 21.4\ kmol/min$

Inlet condition: $y_0 = \frac{h_r\,p^*_{H_2O}(38°C)}{P} = \frac{0.97(49.692\,mmHg)}{760\,mmHg}$

$= 0.0634$ mol H_2O/mol

outlet condition: $y_1 = \frac{p^*_{H_2O}(18°C)}{P} = \frac{15.477\,mmHg}{760\,mmHg}$

$= 0.0204$ mol H_2O/mol

Dry air balance: $(1-0.0634)\dot{n}_0 = (1-0.0204)21.4$

$\dot{n}_0 = 22.4 \text{ kmol/min}$

water balance: $(0.0634)(22.4) = \dot{n}_2 + (0.0204)21.4$

$\dot{n}_2 = 0.98 \text{ kmol/min}$

$\frac{0.98 \text{ kmol}}{\text{min}} \times \frac{18.02 \text{ kg}}{\text{kmol}}$

$= 17.66 \frac{\text{kg}}{\text{min}}$ H_2O condences

b) Enthalpies: $\hat{H}_{air}(38°C) = 0.0291(38-25) = 0.3783 \text{ kJ/mol}$

$\hat{H}_{air}(18°C) = 0.0291(18-25) = 0-0.204 \text{ kJ/mol}$

$\hat{H}_{H_2O}(v, 38°C) = 2570.8 \frac{\text{kJ}}{\text{kg}} \times \frac{1 \text{ kg}}{10^3 \text{ g}} \times \frac{18.02 \text{ g}}{\text{mol}}$

$= 46.33 \text{ kJ/mol}$

$\hat{H}_{H_2O}(v, 18°C) = 2534.5 \frac{\text{kJ}}{\text{kg}} \times \frac{1 \text{ kg}}{10^3 \text{ g}} \times \frac{18.02 \text{ g}}{\text{mol}}$

$= 45.67 \text{ kJ/mol}$

$\hat{H}_{H_2O}(l, 18°C) = 75.5 \frac{\text{kJ}}{\text{kg}} \times \frac{1 \text{ kg}}{10^3 \text{ g}} \times \frac{18.02 \text{ g}}{\text{mol}}$

$= 1.36 \text{ kJ/mol}$

Energy balance: $\Delta \hat{E}_p$, $W_s = 0$ $\Delta E_k = 0$

$$Q = \Delta H = \sum_{out} n_i \hat{H}_i - \sum_{in} n_i \hat{H}_i$$

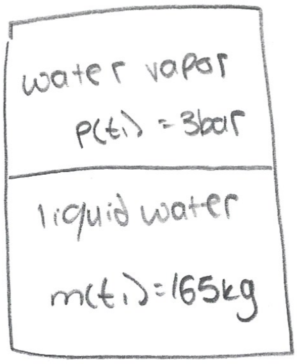
$$= (1-0.0204)(21.4\times10^3)(-0.20) + (0.0204)(21.4\times10^3)($$
$$+ (0.98\times10^3)(1.36) - (1-0.0634)(22.4\times10^3)(0.3783) -$$
$$(0.0634)(22.4\times10^3)(46.33)$$

$$= -5.67\times10^4 \text{ kJ/min}$$

$$5.67\times10^4 \frac{\text{kJ}}{\text{min}} \times \frac{60 \text{ min}}{\text{h}} \times \frac{0.9486 \text{ Btu}}{\text{kJ}} \times \frac{1 \text{ ton cooling}}{12000 \text{ Btu}}$$

= 270 tons of cooling

3.



$V = 200\ L$

$P_{max} = 20\ bar$

a) from steam tables

$T_1(3\ bar,\ sat'd) = \boxed{133.5\ °C}$

$\hat{V}_l(3\ bar,\ sat'd) = 0.001074\ m^3/kg$

$\hat{V}_v(3\ bar,\ sat'd) = 0.606\ m^3/kg$

The total volume is equal to the volume occupied by the liquid plus the head space

$$V_{liquid} = 165kg\left(\frac{0.001074\ m^3}{1kg}\right)\left(\frac{1000L}{1m^3}\right) = \boxed{177.2L}$$

$V_{space} + V_{liquid} = 200L$

$V_{space} = 200 - 177.2$

$\boxed{= 22.8L}$

$$m_v = 22.8L\left(\frac{1m^3}{1000L}\right)\left(\frac{1kg}{0.606m^3}\right)$$

$= \boxed{0.0376\ kg}$

b) At t_2, P=20.0 bar

T_2(20 bar, sat'd) = 212.4°C

$\hat{V}_l$(20 bar, sat'd) = 0.001177 m^3/kg

$\hat{V}_v$(20 bar, sat'd) = 0.0995 m^3/kg

if the liquid water is completely evaporated, volume would be:

$$V = 165\,kg\left(\frac{0.0995\,m^3}{1\,kg}\right)\left(\frac{1000\,L}{1\,m^3}\right)$$

$= 16417.5\,L$

this volume is much larger than total V (200 L) so some liquid water remains and the system is saturated.

T(t_2) = T(20 bar, sat'd)
= 212.4°C

m_{total} = 165 + 0.0376
= 165.0376 kg

$V_l + V_v = 200L$

$m_l\hat{V}_l + (m_{total} - m_l)\hat{V}_v = 200L$

$m_l(0.001177\,\frac{m^3}{kg}) + (165.04 - m_l)(0.0995\,\frac{m^3}{kg}) = 200L \times \frac{1}{10}$

m_l = 164.98 kg

m_v = 0.06 kg

$V_e = 164.98(0.001177)$

$V_L = 194.2L$

$V_{space} = 200 - 194.2$

$V_{space} = 5.8L$

$m_{evap} = m_v(t_2) - m_v(t_1)$

$= 0.06 - 0.0376$

$m_{evap} = 0.022kg$

e) $\Delta E_p, \Delta E_k, W = 0$ because closed system

$U_{final} = 164.98kg(906.2 kJ/kg) + 0.06kg(2598.2 kJ/kg)$

$U_{final} = 149660 kJ$

$U_{initial} = 165 kg(561.1 kJ/kg) + 0.0376kg(2543 kJ/kg)$

$U_{initial} = 92677.1 kJ$

$\Delta U = 149660 - 92677.1$

$= 5.7 \times 10^4 kJ$

$Q = \Delta U = 5.7 \times 10^4 kJ$